



**QUEEN'S  
UNIVERSITY  
BELFAST**

## **A dip or a dab: assessing the efficacy of Virasure® Aquatic disinfectant to reduce secondary spread of the invasive curly waterweed *Lagarosiphon major***

Cuthbert, R. N., Coughlan, N. E., Crane, K., Caffrey, J. M., MacIsaac, H. J., & Dick, J. T. A. (2018). A dip or a dab: assessing the efficacy of Virasure® Aquatic disinfectant to reduce secondary spread of the invasive curly waterweed *Lagarosiphon major*. *Management of Biological Invasions*, 9(3).  
<https://doi.org/10.3391/mbi.2018.9.3.08>

**Published in:**  
Management of Biological Invasions

**Document Version:**  
Publisher's PDF, also known as Version of record

**Queen's University Belfast - Research Portal:**  
[Link to publication record in Queen's University Belfast Research Portal](#)

### **Publisher rights**

Copyright 2018 the authors.  
This is an open access article published under a Creative Commons Attribution License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the author and source are cited.

### **General rights**

Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

### **Take down policy**

The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact [openaccess@qub.ac.uk](mailto:openaccess@qub.ac.uk).

## Research Article

## A dip or a dab: assessing the efficacy of Virasure® Aquatic disinfectant to reduce secondary spread of the invasive curly waterweed *Lagarosiphon major*

Ross N. Cuthbert<sup>1,\*</sup>, Neil E. Coughlan<sup>1</sup>, Kate Crane<sup>1</sup>, Joe M. Caffrey<sup>2</sup>, Hugh J. MacIsaac<sup>3</sup> and Jaimie T.A. Dick<sup>1</sup>

<sup>1</sup>Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Medical Biology Centre, 97 Lisburn Road, Belfast, BT9 7BL, Northern Ireland

<sup>2</sup>INVAS Biosecurity, 6 Lower Ballymount Road, Walkinstown, Dublin 12, Ireland

<sup>3</sup>Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, N9B 3P4, Canada

Author e-mails: [rcuthbert03@qub.ac.uk](mailto:rcuthbert03@qub.ac.uk) (RNC), [neil.coughlan.zoology@gmail.com](mailto:neil.coughlan.zoology@gmail.com) (NEC), [kcrane02@qub.ac.uk](mailto:kcrane02@qub.ac.uk) (KC), [joecaffrey@invas.ie](mailto:joecaffrey@invas.ie) (JMC), [hughm@uwindsor.ca](mailto:hughm@uwindsor.ca) (HJM), [j.dick@qub.ac.uk](mailto:j.dick@qub.ac.uk) (JTAD)

\*Corresponding author

Received: 6 March 2018 / Accepted: 27 May 2018 / Published online: 5 July 2018

Handling editor: Calum MacNeil

### Abstract

Aquatic alien invasive species (AIS) are a substantial and increasing threat to biodiversity and ecosystem function worldwide. In particular, invasive aquatic macrophytes, such as the South African curly waterweed *Lagarosiphon major* ((Ridley) Moss 1928), induce major environmental change that often culminates in wide-ranging ecological and socio-economic impacts. Currently, there is a lack of effective biosecurity protocols to mitigate against such invader spread. Here, we examine the efficacy of a broad-spectrum aquatic disinfectant, Virasure® Aquatic, to induce mortality of *L. major* propagule stages. We assessed the efficacy of Virasure® Aquatic at contact times of 1, 2 and 5 minutes, using 1% (10g L<sup>-1</sup>) and 4% (40g L<sup>-1</sup>) concentrations. A necrosis scale was applied to visually assess tissue degradation. Necrosis increased with longer chemical contact times, with fragment degradation optimised at 2 minutes at 1% concentration and 1 minute at 4% concentration. Mode of application was also critical to treatment effectiveness, with spray treatments less effective than submersion treatments. We recommend the use of Virasure® Aquatic *via* submersion for a minimum period of 2 minutes at 1% concentration or higher. While spray applications should be applied when submersion is not feasible, such as with large water craft, increased spray times beyond those assessed here should be examined. However, results presented suggest that Virasure® Aquatic can effectively reduce the secondary spread of invasive *L. major*, and may thus form an integral part of biosecurity protocols. The use of broad-spectrum disinfectants and other readily available treatments, that were not purposefully developed for aquatic AIS control but nevertheless are emerging as effective in aquatic AIS management, is discussed and encouraged.

**Key words:** biosecurity, aquatic disinfectant, invasive species management, potassium peroxymonosulfate, spread prevention, macrophyte

### Introduction

Aquatic alien invasive species (AIS) are considered a major driver of adverse change to freshwater ecosystems (Simberloff et al. 2013; Piria et al. 2017). In particular, many invasive aquatic plants (especially invasive macrophytes) detrimentally affect freshwater community dynamics and ecosystem function *via* negative alteration of biotic and abiotic conditions (Schultz and Dibble 2012; Hussner 2014; Kuehne et al. 2016). In addition, the considerable biomass

associated with the presence of large monospecific swards of invasive macrophytes can inhibit many recreational and commercial activities, increase flooding frequency, and result in substantial economic costs (Williams et al. 2010; Lafontaine et al. 2013). Novel methods for invader eradication and control, which balance efficacy with cost, legislative barriers and non-target effects, are thus urgently required.

Despite a restricted ability to self-disperse, many aquatic AIS continue to successfully invade hydrologically unconnected sites (Hussner 2012; Caffrey et al.

2016; Coughlan et al. 2017a). While vectors that underpin the natural dispersal of aquatic AIS are often not fully determined (Coughlan et al. 2017b), freshwater systems remain highly vulnerable to accidental invader introductions due to their inter-connectedness and exposure to multiple transport vectors, e.g. angling and boating (Rothlisberger et al. 2010; Banha et al. 2016). To date, various stakeholder biosecurity campaigns (e.g. “Check, Clean, Dry”) have attempted to reduce the spread of aquatic AIS (Anderson et al. 2015) by creating awareness and endorsing best practice. Moreover, recent European Union (EU) legislation (Regulation 1143/2014) requires EU Member States (MS) to enforce rapid control, spread prevention and eradication of damaging invaders that are listed as Invasive Alien Species of Union Concern. Furthermore, recent United States of America (USA) legislation (Safeguarding the Nation from the Impacts of Invasive Species – amendment to Executive Order 13112) seeks to prevent, control and eradicate invasive species.

Currently, management options for the eradication and control of established invader populations are often complex, resource-intensive and costly, and achieve only limited success (Hussner et al. 2017; Piria et al. 2017). Indeed, there are relatively few examples of successful reductions and/or eradications where invaders have already established (Hussner et al. 2017). As prevention of aquatic AIS introductions is the most economical way to safeguard ecosystems, the development of efficient and cost-effective biosecurity protocols that prevent invader spread is essential (Barbour et al. 2013; Simberloff et al. 2013; Caffrey et al. 2016; Hussner et al. 2017; Coughlan et al. 2018a). Presently, however, there exists only a limited understanding of the relative efficacies of various biosecurity measures (Barbour et al. 2013; Anderson et al. 2015; Piria et al. 2017; Coughlan et al. 2018a). Chemical treatment has been suggested as a suitable mechanism to control aquatic AIS spread, as this is often more economical and widely applicable when compared to other methods (Getsinger et al. 2008; Richardson et al. 2016). However, chemical treatments have hitherto been predominantly applied *in situ* where invasive populations have already established (e.g. glyphosate, Emerine et al. 2010; metsulfuron, Clements et al. 2014), often with inconsistent rates of success (see Hussner et al. 2017). Thus, innovative measures to reduce invasive species spread are urgently required (e.g. Coughlan et al. 2018b). While alternative broad-spectrum aquatic disinfectants may prove effective at reducing secondary spread of invaders, these chemicals have yet to be thoroughly considered as aquatic AIS biosecurity agents.

*Lagarosiphon major* ((Ridley) Moss 1928) is a canopy-forming submerged invasive macrophyte, native to South Africa (Caffrey et al. 2010). In the Northern Hemisphere, *L. major* displays over-winter growth and can achieve substantial biomass under conditions that are unsuitable for many native species, including within eutrophic waters (Martin and Coetzee 2014). Despite being listed as an EU Invasive Alien Species of Union Concern, *L. major* is still commonly sold as an oxygenating plant for aquaria and artificial watercourses. Like many invasive macrophytes, *L. major* predominantly reproduces and spreads by vegetative propagation, particularly *via* vegetative fragments which have been observed to exhibit a high survival potential (Redekop et al. 2016; Coughlan et al. 2018a). Moreover, given the high level of fragmentary propensity associated with *L. major*, propagules are commonly observed to be transferred *via* boat motors and fishing nets (Matthews et al. 2012).

Here, we assess the efficacy of Virasure® Aquatic as a biosecurity agent to reduce the secondary spread of *L. major* fragments under varied chemical concentrations, exposure times and modes of application. While aquatic disinfectants had previously been developed for applications outside of invasive species management, several have been observed to effectively and rapidly induce aquatic AIS mortality (e.g. Virkon®/Asian clam; Barbour et al. 2013), but none have been previously tested upon invasive macrophytes.

## Methods

### *Cultivation of Lagarosiphon major*

Shoot portions of *L. major* were harvested from an artificial pond at Greenacres Golf Centre, Ballyclare, Northern Ireland (N54°43'28.631; W06°00'10.908), between February and April 2016. Substrate was also sampled from the collection site for use in laboratory cultures and the experiment using a spade. Vegetative samples were rinsed and transported to Queen's University Belfast in dechlorinated tap water. *Lagarosiphon major* was maintained in continuously aerated aquaria within the laboratory at  $13 \pm 2$  °C under a 12:12 light:dark regime. All plants were acclimatised for one week prior to experimentation.

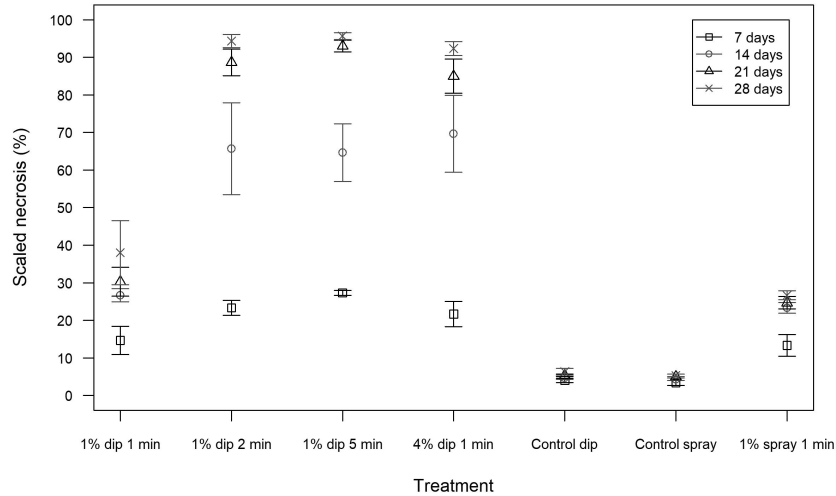
### *Efficacy of Virasure® Aquatic as a biosecurity agent for Lagarosiphon major*

Healthy apical shoot sections of *L. major* were selected for submersion and spray treatments with Virasure® Aquatic (Fish Vet Group, 22 Carsegate Road,

**Table 1.** Scale describing visual tissue degradation stages of *Lagarosiphon*.

Scale	Description
0–10%	Tissue degradation at site of fragmentation
10–20%	Pale brown leaf at apical tip
20–30%	Pale brown leaf ends anywhere on plant
30–40%	All leaf ends pale brown
40–50%	Fragment collapse < 90°
50–60%	Full leaves pale brown
60–70%	All full leaves pale brown
70–80%	Fragment collapse ≥ 90°
80–90%	Full leaves dark brown/fragmenting at tips
90–100%	Full fragment degradation: leaves fragmented and dark, flattened against stem

**Figure 1.** Mean (± SE) necrosis of *Lagarosiphon major* propagule fragments over a 28 day period post-exposure to 1% Virasure® Aquatic for 1, 2 and 5 minutes *via* submersion; to 4% Virasure® Aquatic for 1 minute *via* submersion; and to 1% Virasure® Aquatic for 1 minute *via* continual spray, alongside control submersion and spray treatments (*n* = 3).



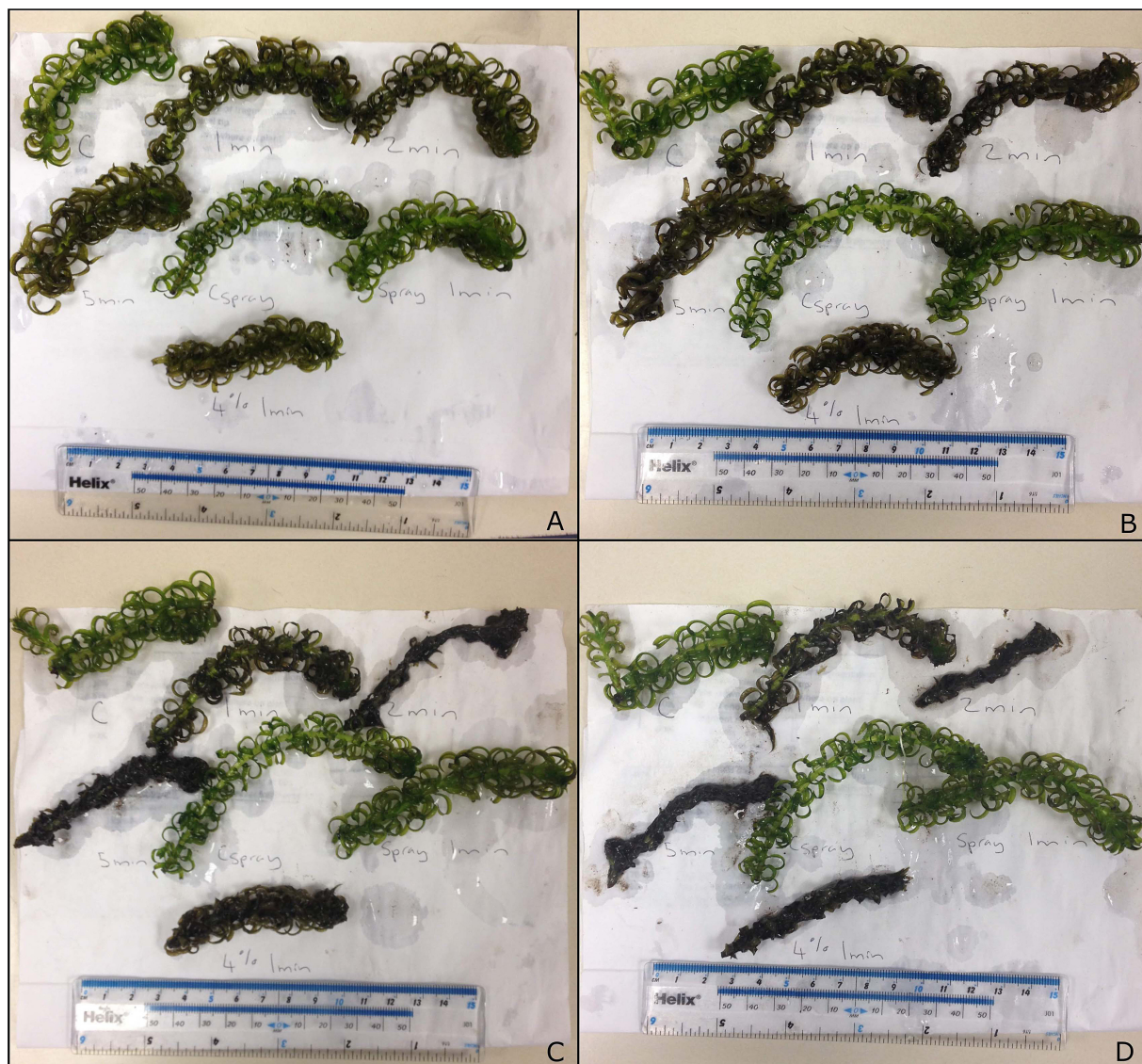
Inverness, Scotland, IV3 8EX). A necrosis scale was developed to monitor tissue degradation following the various exposure treatments (see Table 1). Individual 5 cm apical fragments of *L. major* were either submerged in a 1% Virasure® Aquatic (10 g L<sup>-1</sup>) solution for 1, 2 or 5 minute exposure, or were submerged in a 4% Virasure® Aquatic (40 g L<sup>-1</sup>) solution for 1 minute exposure. Control samples were submerged in dechlorinated tap water for 1 minute. Other 5 cm fragments were concurrently sprayed continually with 1% Virasure® Aquatic solution for 1 minute, while control samples were sprayed with dechlorinated tap water for 1 minute. All treatments were replicated three times. Following treatment, each fragment was individually submerged in dechlorinated tap water in 0.15 litre cylindrical containers measuring 8 cm diameter, with sufficient substrate to cover the basal area to monitor recovery. Further, comparative photographs were taken weekly to support visual estimation of tissue degradation. All experiments were conducted in a randomised design.

Statistical analyses

All data analyses were undertaken in R version 3.4.2. (R Core Team 2017). We analysed categorically scaled necrosis (Table 1) with repeated measures using ordinal logistic regression. Experimental observations for treatment effectiveness spanned 28 days at weekly intervals, with explanatory variables “treatment” and “time” incorporated as both single and interacting terms in the model. Tukey’s comparisons were used to perform *post hoc* analyses where terms yielded significance.

Results

Minimal fragment degradation was observed for both control treatments (Figure 1; Figure 2). However, Virasure® Aquatic significantly increased fragment tissue degradation ( $\chi^2 = 73.46$ , *df* = 6, *P* < 0.001; Figure 1). Even submergence or spraying for 1 minute in 1% Virasure® Aquatic resulted in significant fragment degradation (submergence, *z* = 5.89, *P* < 0.001;



**Figure 2.** *Lagarosiphon major* propagule fragments at 7 (A), 14 (B), 21 (C) and 28 (D) days post-treatment with Virasure® Aquatic. Top row (L–R): control submerged 1 minute, submerged 1 minute (1%), submerged 2 minutes (1%). Middle row (L–R): submerged 5 minutes (1%), control spray 1 minute, spray 1 minute (1%). Bottom: submerged 1 minute (4%). Photographs by RNC.

spraying,  $z = 5.86$ ,  $P < 0.001$ ). While there was no difference between submergence or spray treatments for 1 minute with 1% Virasure® Aquatic ( $z = 1.50$ ,  $P = 0.74$ ), submergence for 2 minutes in 1% Virasure® Aquatic was significantly more effective than both 1 minute submergence ( $z = 9.56$ ,  $P < 0.001$ ) and spraying ( $z = 11.79$ ,  $P < 0.001$ ). However, there was no significant difference between 2 minute submergence and 5 minute submergence in 1% Virasure® Aquatic ( $z = 1.08$ ,  $P = 0.93$ ), nor when compared to 1 minute submergence in 4% Virasure® Aquatic (2 minutes,  $z = 0.19$ ,  $P = 0.99$ ; 5 minutes,  $z = 1.20$ ,  $P = 0.89$ ).

Overall, necrosis increased with time after treatment ( $\chi^2 = 86.82$ ,  $df = 3$ ,  $P < 0.001$ ; Figure 2). There was a significant difference between degradation observed between all incremental observation periods (all  $P \leq 0.002$ ). There was a significant “treatment  $\times$  time” interaction ( $\chi^2 = 98.82$ ,  $df = 18$ ,  $P < 0.001$ ), which reflected the relatively rapid attainment of full degradation with longer exposure time and greater chemical concentration, whilst controls survived (Figure 1). Although not accounted for quantitatively, regrowth of shoots was observed within control fragments and fragments treated with 1% Virasure®



Aquatic *via* spray only, indicating sustained fragment viability of control and spray treatments, but not submersion treatments (Figure 2).

## Discussion

Aquatic alien invasive species (AIS) continue to spread at unprecedented rates, reducing biodiversity and altering ecosystem function (Seebens et al. 2017, 2018). As aquatic ecosystems are highly susceptible to aquatic AIS introductions, the identification and integration of cost-effective and widely-applicable protocols to reduce invader spread is essential. Invasive aquatic plants have exerted particularly profound negative impacts on recipient ecological communities (Schultz and Dibble 2012; Hussner 2014; Kuehne et al. 2016). Virasure® Aquatic can induce substantial necrosis, morbidity and mortality of *L. major* fragmentary propagules. Accordingly, biosecurity protocols can likely be improved with the use of this broad-spectrum aquatic disinfectant. To date, research has largely focused on the efficacy of Virkon® Aquatic, a similar aquatic disinfectant, to control aquatic AIS such as Asian clam, *Corbicula fluminea* (Barbour et al. 2013), quagga mussel, *Dreissena rostriformis bugensis* (Moffitt et al. 2015), and the gastropod red-rimmed melania, *Melanoides tuberculata* (Mitchell et al. 2007), all under varying exposure times. Treatment of submerged plants using herbicides is strictly prohibited across Europe due to adverse environmental impacts, thus inherently restricting management options for aquatic AIS (Hussner et al. 2017). Accordingly, the use of aquatic disinfectants outside of water, to reduce secondary spread of invaders, is pertinent, timely and more environmentally friendly.

A 2 minute submersion using 1% Virasure® Aquatic solution can achieve full *L. major* fragment degradation. However, longer exposure times and greater chemical concentrations will likely increase the rapidity of fragment mortality. When submersion is not feasible, a spray treatment should be applied using longer contact times than assessed within the scope of the present study, and a higher concentration ( $\geq 4\%$  solution) should be applied. The limited efficacy of shorter submersion in, or spraying treatments with, 1% Virasure® Aquatic solution may result from a lack of adherence to plant tissue. These results corroborate with those of Paetzold and Davidson (2011), wherein an invasive sea squirt was found to be largely unaffected by spray treatments with Virkon® Aquatic.

In the present study, we examined relatively large plant fragments as these are known to exhibit a greater capacity for regrowth (Wu et al. 2007; Jiang

et al. 2009), and also reduce inhibition of lateral growth driven through apical dominance (Cline 1991). Yet, the size of fragments examined is still likely within the threshold of propagules which are readily entangled with, and transported overland by, anthropogenic vectors (Barrat-Segretain et al. 1998). The lack of root growth observed here may be a result of the timescale permitted, poor anchorage, or potential apical dominance of samples (Cline 1991; Wu et al. 2007). Critically, our results demonstrate that the application of Virasure® Aquatic can induce substantial and complete degradation of *L. major* propagules. The working pH for the main oxidising ingredient (potassium peroxymonosulfate) of Virasure® Aquatic is strongly acidic (2.6) when diluted in a 1% solution at 20 °C, facilitated through the presence of two organic, malic and sulphamic, acids (see Fish Vet Group 2015). However, *L. major* may only be particularly susceptible to these compounds due to the species' characteristic tendency to induce and tolerate high levels of alkalinity (Stiers et al. 2011). Furthermore, negligible toxicities to non-target vertebrate species following short-term exposure to a compositionally-similar aquatic disinfectant have been demonstrated (Stockton-Fiti and Moffitt 2017), and therefore the focal product may be safe for use proximal to water.

Our promising results suggest further experimental examination of the efficacy of aquatic disinfectants to reduce aquatic AIS spread to be critical. Accordingly, additional trials investigating the impacts of such chemical solutions on aquatic AIS propagule stages should be considered, alongside assessments for potential non-target effects on other native species, particularly macroinvertebrates associated with aquatic macrophytes. Further aquatic disinfectant efficacy examinations towards other existing and emerging floral and faunal aquatic AIS are urgently required. Disinfectant trials should concurrently seek to examine different contact times, recovery conditions and varied chemical concentrations upon a variety of anthropogenic vectors, such as equipment associated with angling and boating, in order to maximise the transparency of results. Finally, the incorporation of aquatic disinfectants within biosecurity management protocols requires urgent consideration by stakeholder groups.

## Acknowledgements

RNC obtained funding support from Queen's University Belfast for this study. NEC and JTAD are supported by the Irish EPA research grant 2015-NC-MS-4. KC is supported through contributions from Queen's University Belfast, the University of Windsor and McGill University. We additionally acknowledge funding received from NERC. We graciously thank Dr Matthijs Metselaar at Fish Vet Group for providing Virasure® Aquatic. We also thank all staff at the Greenacres Golf Centre.

## Author contributions

RNC, KC, JMC and JTAD designed the study; RNC conducted the experiment and data analysis; RNC produced the first draft of the manuscript; all authors contributed to writing the manuscript, which was led by RNC.

## References

- Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD (2015) Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biological Invasions* 17: 2287–2297, <https://doi.org/10.1007/s10530-015-0875-6>
- Banha F, Gimeno I, Lanao M, Touya V, Durán C, Peribáñez M, Anastácio P (2016) The role of waterfowl and fishing gear on zebra mussel larvae dispersal. *Biological Invasions* 18: 115–125, <https://doi.org/10.1007/s10530-015-0995-z>
- Barbour JH, McMenamin S, Dick JTA, Alexander ME, Caffrey JM (2013) Biosecurity measures to reduce the spread of the invasive freshwater Asian clam, *Corbicula fluminea* (Müller, 1774). *Management of Biological Invasions* 4: 219–230, <https://doi.org/10.3391/mbi.2013.4.3.04>
- Barrat-Segretain MH, Bornette G, Hering-Vilas-Bóas A (1998) Comparative abilities of vegetative regeneration among aquatic plants growing in disturbed habitats. *Aquatic Botany* 60: 201–211, [https://doi.org/10.1016/S0304-3770\(97\)00091-0](https://doi.org/10.1016/S0304-3770(97)00091-0)
- Caffrey JM, Millane M, Evers S, Moran H, Butler M (2010) A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions* 5: 123–129, <https://doi.org/10.3391/ai.2010.5.2.01>
- Caffrey JM, Dick JTA, Lucy FE, Davis E, Niven A, Coughlan NE (2016) First record of the Asian clam *Corbicula fluminea* (Müller, 1774) (Bivalvia, Cyrenidae) in Northern Ireland. *BiolInvasions Records* 5: 239–244, <https://doi.org/10.3391/bir.2016.5.4.08>
- Clements D, Dugdale TM, Butler KL, Hunt TD (2014) Management of aquatic alligator weed (*Alternanthera philoxeroides*) in an early stage of invasion. *Management of Biological Invasions* 5: 327–339, <https://doi.org/10.3391/mbi.2014.5.4.03>
- Cline MG (1991) Apical dominance. *The Botanical Review* 57: 318–358, <https://doi.org/10.1007/BF02858771>
- Coughlan NE, Kelly TC, Davenport J, Jansen MAK (2017a) Up, up and away: bird-mediated ectozoochorous dispersal between aquatic environments. *Freshwater Biology* 62: 631–648, <https://doi.org/10.1111/fwb.12894>
- Coughlan NE, Stevens AL, Kelly TC, Dick JTA, Jansen MAK (2017b) Zoochorous dispersal of freshwater bivalves: an overlooked vector in biological invasions? *Knowledge and Management of Aquatic Ecosystems* 418: 42, <https://doi.org/10.1051/kmae/2017037>
- Coughlan NE, Cuthbert RN, Kelly TC, Jansen MAK (2018a) Parched plants: viability of invasive aquatic macrophytes following exposure to various desiccation regimes. *Aquatic Botany* 150: 9–15, <https://doi.org/10.1016/j.aquabot.2018.06.001>
- Coughlan NE, Walsh DA, Caffrey JM, Davis E, Lucy FE, Cuthbert RN, Dick JTA (2018b) Cold as Ice: a novel eradication and control method for invasive Asian clam, *Corbicula fluminea*, using pelleted dry ice. *Management of Biological Invasions* (in press)
- Emerine SE, Richardson RJ, True SL, West AM, Roten RL (2010) Greenhouse response of six aquatic invasive weeds to Imazamox. *Journal of Aquatic Plant Management* 48: 105–111
- Fish Vet Group (2015) Safety data sheet Virasure® Aquatic version number 2. Fish Vet Group, Inverness, UK, 8 pp
- Getsinger KD, Netherland MD, Grue CE, Koschnick TJ (2008) Improvements in the use of aquatic herbicides and establishment of future research directions. *Journal of Aquatic Plant Management* 46: 32–41
- Hussner A (2012) Alien aquatic plants in European countries. *Weed Research* 52: 397–406, <https://doi.org/10.1111/j.1365-3180.2012.00926.x>
- Hussner A (2014) Long-term macrophyte mapping documents a continuously shift from native to non-native aquatic plant dominance in the thermally abnormal River Erft (North Rhine-Westphalia, Germany). *Limnologia* 48: 39–45, <https://doi.org/10.1016/j.limno.2014.05.003>
- Hussner A, Stiers I, Verhofstad MJM, Bakker ES, Grutters BMC, Haury J, van Valkenburg JLCH, Brundu G, Newman J, Clayton JS, Anderson LWJ, Hofstra D (2017) Management and control methods of invasive alien aquatic plants: a review. *Aquatic Botany* 136: 112–137, <https://doi.org/10.1016/j.aquabot.2016.08.002>
- Jiang J, An S, Zhou C, Guan B, Sun Z, Cai Y, Liu F (2009) Fragment propagation and colonization ability enhanced and varied at node level after escaping from apical dominance in submerged macrophytes. *Journal of Integrated Plant Biology* 51: 308–315, <https://doi.org/10.1111/j.1744-7909.2008.00732.x>
- Kuehne LM, Olden JD, Rubenson ES (2016) Multi-trophic impacts of an invasive aquatic plant. *Freshwater Biology* 61: 1846–1861, <https://doi.org/10.1111/fwb.12820>
- Lafontaine RM, Beudels-Jamar RC, Delsinne T, Robert H (2013) Risk analysis of the Curly Waterweed *Lagarosiphon major* (Ridley) Moss. Risk analysis report of non-native organisms in Belgium from the Royal Belgian Institute of Natural Sciences for the Federal Public Service Health, Food Chain Safety and Environment, Belgium, 35 pp
- Martin GD, Coetzee JA (2014) Competition between two aquatic macrophytes, *Lagarosiphon major* (Ridley) Moss (Hydrocharitaceae) and *Myriophyllum spicatum* Linnaeus (Haloragaceae) as influenced by substrate sediment and nutrients. *Aquatic Botany* 114: 1–11, <https://doi.org/10.1016/j.aquabot.2013.11.001>
- Matthews J, Beringen R, Collas FPI, Koopman KR, Odé B, Pot R, Sparrius LB, van Valkenburg JLCH, Verbrugge LNH, Leuven RSEW (2012) Risk analysis of non-native Curly Waterweed (*Lagarosiphon major*) in the Netherlands. Reports Environmental Science 418, Netherlands, 32 pp
- Mitchell AJ, Hobbs MS, Brandt TM (2007) The effect of chemical treatments on red-rim melania *Melanoides tuberculata*, an exotic aquatic snail that serves as a vector of trematodes to fish and other species in the USA. *North American Journal of Fish Management* 27: 1287–1293, <https://doi.org/10.1577/M06-252.1>
- Moffitt CM, Barenberg A, Stockton KA, Watten BJ (2015) Efficacy of two approaches for disinfecting surfaces and water infested with quagga mussel veligers. In: Wong WH, Gertszenberger S (eds), Biology and Management of Invasive Quagga and Zebra Mussels in the Western United States, CRC Press, USA, pp 467–477, <https://doi.org/10.1201/b18447-38>
- Paetzold SC, Davidson J (2011) Aquaculture fouling: Efficacy of potassium monopersulphate triple salt based disinfectant (Virkon® Aquatic) against *Ciona intestinalis*. *Biofouling* 27: 655–665, <https://doi.org/10.1080/08927014.2011.594503>
- Pirai M, Copp GH, Dick JTA, Duplić A, Groom Q, Jelić D, Lucy FE, Roy HE, Sarat E, Simonović P, Tomljanović T, Tricarico E, Weinlander M, Adámek Z, Bedolfe S, Coughlan NE, Davis E, Dobrzycka-Krahel A, Grgić Z, Kirankaya ŞG, Ekmekçi FG, Lajtner J, Lukas JAY, Koutsikos N, Mennen GJ, Mitíć B, Pastorino P, Ruokonen TJ, Skóra ME, Smith ERC, Šprem N, Tarkan AS, Treer T, Vardakas L, Vehanen T, Vilizzi L, Zanella D, Caffrey JM (2017) Tackling invasive alien species in Europe II: threats and opportunities until 2020. *Management of Biological Invasions* 8: 273–286, <https://doi.org/10.3391/mbi.2017.8.3.02>
- R Core Team (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
- Redekop P, Hofstra D, Hussner A (2016) *Elodea canadensis* shows a higher dispersal capacity via fragmentation than *Egeria densa* and *Lagarosiphon major*. *Aquatic Botany* 130: 45–49, <https://doi.org/10.1016/j.aquabot.2016.01.004>

- Richardson RJ, Haug EJ, Netherland MD (2016) Response of seven aquatic plants to a new arylpicolinate herbicide. *Journal of Aquatic Plant Management* 54: 26–31
- Rothlisberger JD, Chadderton WL, McNulty J, Lodge DM (2010) Aquatic invasive species transport via trailered boats: what is being moved, who is moving it, and what can be done. *Fisheries* 35: 121–132, <https://doi.org/10.1577/1548-8446-35.3.121>
- Schultz R, Dibble E (2012) Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. *Hydrobiologia* 684: 1–14, <https://doi.org/10.1007/s10750-011-0978-8>
- Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Shyama Pagad, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke A, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. *Nature Communications* 8: 14435, <https://doi.org/10.1038/ncomms14435>
- Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke J, Pagad S, Pyšek P, van Kleunen M, Winter M, Ansong M, Arianoutsou M, Bacher S, Blasius B, Brockerhoff EG, Brundu G, Capinha C, Causton CE, Celesti-Grapow L, Dawson W, Dullinger S, Economo EP, Fuentes N, Guénard B, Jäger H, Kartesz J, Kenis M, Kühn I, Lenzner B, Liebhold AM, Mosena A, Moser D, Nentwig W, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, Walker K, Ward DF, Yamanaka T, Essl F (2018) Global rise in emerging alien species results from increased accessibility of new source pools. *Proceedings of the National Academy of Sciences* 115: E2264–E2273, <https://doi.org/10.1073/pnas.1719429115>
- Simberloff D, Martin J, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Berthou E, Pascal M (2013) Impacts of biological invasions: what's what and the way forward. *Trends in Ecology and Evolution* 28: 58–66, <https://doi.org/10.1016/j.tree.2012.07.013>
- Stiers I, Njambuya J, Triest L (2011) Competitive abilities of invasive *Lagarosiphon major* and native *Ceratophyllum demersum* in monocultures and mixed cultures in relation to experimental sediment dredging. *Aquatic Botany* 95: 161–166, <https://doi.org/10.1016/j.aquabot.2011.05.011>
- Stockton-Fiti KA, Moffitt CM (2017) Safety and efficacy of Virkon® aquatic as a control tool for invasive Molluscs in aquaculture. *Aquaculture* 480: 71–76, <https://doi.org/10.1016/j.aquaculture.2017.08.005>
- Williams F, Eschen R, Harris A, Djeddour D, Pratt C, Shaw RS, Murphy ST (2010) The economic cost of invasive non-native species on Great Britain. CABI report, UK, 199 pp
- Wu Z, Zuo J, Ma J, Wu J, Cheng S, Liang W (2007) Establishing submersed macrophytes via sinking and colonization of shoot fragments clipped off manually. *Wuhan University Journal of Natural Sciences* 12: 553–557, <https://doi.org/10.1007/s11859-006-0057-6>